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E-Futures

Mini-project report

Monitoring Carbon Capture in Deep Rock using Muon Tomography

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Monitoring Carbon Capture in Deep Rock using Muon Tomography (Abridged Version)

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1. Introduction

As a result of energy generation, a vast amount of CO_2 is being released by combustion of fossil fuel. Scientific reports have shown that emission of CO_2 is the cause of climate change[1] and acidification of sea water[2]. Both phenomena are seriously affecting the ecosystem, which could possibly cause extinction of various spices. To tackle such problems, the British government has passed the Climate Change Act in 2008, which set the emission cut target to 80% by 2050. Interests in renewable technology have grown rapidly since and extensive researches and development are improving renewable technologies.

However, due to practical feasibility and financial difficulties, renewable sources are unlikely to be the main energy source of the UK in the near future. Fossil fuel will still be the predominant energy source of Britain for now. Despite this, it is still possible to reduce CO_2 emission and meet energy demand at the same time by using fossil fuel with carbon capture and sequestration/storage (CCS) method.

2. Literature Review

2.1 About CCS technologies

CCS technologies include methods of removing CO_2 either before or after combustion, then storing the removed CO_2 by either mechanical or chemical methods. There are three components in CCS: capture, transport and storage. There are many novel storage technologies which are under research and development; for example, reacting CO_2 with minerals to form mineral carbonate. At the moment, geological storage is the most promising storage method[3].

Typically, for geological storage, CO_2 will be compressed into liquid and will be injected into the porous storage layer, about 1000 to 2000 meters underground below a layer of cap rock, which is an impermeable rock layer that forms a physical barrier above the storage location. The CO_2 reservoir is usually a rock with high porosity and a lower density comparing to the cap rock[4]. In certain geological formation such as aquifers, water is also present in the reservoir. After injection, four storage mechanisms could possibly take place[5]: Structural storage – physically trapping CO_2 by cap rock; Residual storage – trapping CO_2 by the storage rock pores; Solubility storage – CO_2 dissolving in the brine in the storage layer; Mineral storage– CO_2 reacting with the rock, forming mineral carbonates. The amount of CO_2 stored by each mechanism depends on how long the CO_2 has been stored (see figure 1).

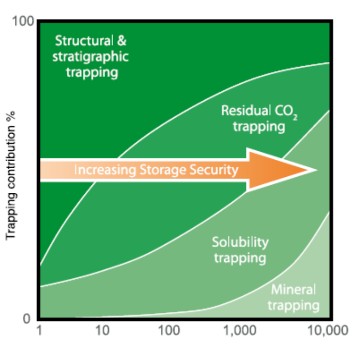

Figure 1 Time and contribution of each mechanism[3]

In order to ensure the CO_2 stored remains in the reservoir and to understand what happens to the CO_2 after injection, it is essential to monitor the reservoir with effective monitoring methods. These methods mainly involve soil sampling, use of tracers, measuring seismic reflection, measuring subsurface responds to electric/electromagnetic wave, measuring gravity responses and pressure monitoring. Different methods have different strength and weaknesses and there is no single method that could meet all requirements. Therefore, normally, more than one method would be used to monitor storage sites.

2.2 Muon tomography and its possible applications

Muons are charged elementary particles which are created as cosmic radiation strikes the atmosphere. As cosmic radiation is always present in space, there is a constant rain of muons on Earth. Muons are very penetrating particles but will lose energy through ionisation when travelling through matter. This ionisation can be detected by scintillators.

The amount of energy loss by muons is proportional to the density of matter and the distance they travelled. Muons could also be deflected when travelling through matter with high density. These two properties of muons were exploited extensively and developed into muon tomography.

Currently, muon tomography is proposed to serve two main purposes. Firstly, it is suggested that muon tomography could be used to detect nuclear contraband and to locate hidden radioactive materials. This suggestion is made based on the scattering of muons when travelling through high-Z (high atomic number) materials[6]. The National Institute for Nuclear Physics in Italy has built a muon tomography prototype and demonstrated that in principle it is capable of reconstructing an image of the shape of the hidden high atomic number material (see fig.3) in specific conditions[7]. Another possible use of muon tomography is to observe the internal structure of a volcano due to change in muon flux in relation to difference in density and distance travelled. The technique was first demonstrated by Tanaka et al in 2007 to observe the Asama volcano in Japan[8]. Similar technique could also be used to find voids in rocks or hidden chambers in pyramids.

Because the principle of muon tomography is based on change in density, therefore it is possible to be used for monitoring a CCS storage site: in case of leak or CO_2 migration, density of reservoir will decrease, which could be signified by an increase of muon intensity at the bottom of the reservoir.

3. MUSUN Calculations

Three sets of calculations were conducted using the computer code MUSUN in order to assess the effectiveness of the technique quantitatively. The first set of calculation determines how sensitivity changes between the shallowest (1km) and deepest (2km) storage site, and how operation time affects the performance of detector. Second set of calculations showed how sensitivity of detector changes with its dimension. The final set of calculations was done using real geological parameter of an existing storage site in order to obtain a rough picture of how the detector would perform in a semi-realistic situation.

Sensitivity of Detector in terms of %CO_2 loss		
Operation time	**1km underground**	**2km underground**
2 Years	**15%**	**Insensitive to leak**
4 Years	**11%**	
10 Years	**6%**	**75%**

Table 1 Summary of results for the first set of calculation

The first set of calculations shows that, by moving the detector from 1km to 2km underground, the number of muons which could be detected drops by 98%. With an operation time of 2 years, the detector is sensitive to a minimum CO_2 loss of 15% at 1km, while at 2 km it is incapable of detecting any leak. Also, with extended operation time, sensitivity of detector improves. Table 1 summarises all the results obtained in the first set of calculations.

The second set of calculation shows that with a bigger surface area, the detector will have improved sensitivity. Table 2 shows summarises the results of this set of calculations.

Dimensions of Detectors and their sensitivity in terms of %CO_2 loss				
	Original Design	**Design 1**	**Design 2**	**Design 3**
Dimension (m×m×m)	**1×1×1**	**5×0.2×0.2**	**10×0.2×0.2**	**20×0.2×0.2**
Top Surface Area (m^2)	**1**	**1**	**2**	**4**
Sensitivity	**75%**	**84%**	**62%**	**44%**

Table 2 Summary of results for the second set of calculations

From the results of both calculations, a relationship between sensitivity and surface area can be derived. Sensitivity of the detector is dependent of relative error σ_r, which is the ratio between the standard deviation of a variable and the value of variable:

$$\sigma_r = \frac{\sqrt{N}}{N} = \frac{1}{\sqrt{N}} \quad (eq.1)$$

Results suggest that number of events depends on operation time t and surface area of detector S, therefore:

$$N \propto St \quad (eq.2)$$

Combining equation 1 and 2 gives a new relationship:

$$\sigma_r \propto \frac{1}{\sqrt{St}} \quad (eq.3)$$

Therefore, relative error is inversely proportional to the square root of the product of surface area and time.

The final set of calculations was conducted with real geological parameters of the Sleipner storage site in Norway. However, it was assumed that no water is present in the reservoir. Therefore the setup is said to be semi-realistic. With this set up, using the original detector design, the detector is sensitive to 13% of minimum CO_2 loss with an operation time of 2 years. If the operation time is extended to 4 years, then the detector is capable of detecting a minimum loss of 9%. Comparing these results to the results obtained in the first set of calculations, the detector is working better in this setup. However, because it is assumed that the reservoir does not contain any water, the results could be slightly optimistic.

4. Conclusions

In this project, the general concepts of CCS technologies and the methodology of geological carbon storage and muon tomography were explained through a literature review. Calculations are done in order to assess the effectiveness of using muon tomography as a carbon storage monitoring method. Results show that, at specific conditions, muon tomography could become an effective monitoring method. However, more calculations should be done in order to optimise the detector's design.

5. References

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